



Europäisches Patentamt  
European Patent Office  
Office européen des brevets

(11) Publication number:

0 101 285  
A2

(12)

## EUROPEAN PATENT APPLICATION

(21) Application number: 83304573.5

(51) Int. Cl.<sup>3</sup>: C 12 N 5/00

(22) Date of filing: 08.08.83

(30) Priority: 09.08.82 JP 138153/82

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(43) Date of publication of application:  
22.02.84 Bulletin - 84/8

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(84) Designated Contracting States:  
DE FR GB IT

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(54) A substratum for cell culture and a method using it.

(55) A substratum for cell culture comprising a chemically modified collagen rich in positive or negative charge in culture condition was prepared by modifying the amino or carboxyl groups respectively of collagen. The chemically modified collagens adhere to and cause proliferation of animal cells much more actively than unmodified collagen in the system of absence or presence of bovine foetal serum. The cultured animal cells can be detached efficiently from the chemical modified collagen, and therefore, the cultured animal cells can be isolated and recovered highly selectively without incurring any injury from the chemically modified collagen.

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## A SUBSTRATUM FOR CELL CULTURE AND A METHOD USING IT

The present invention relates to collagen-derived substrates for cell culture and their use in incubating and isolating cells by using it.

Collagen exists in various organs such as blood vessels, skin, liver, pancreas and kidney as the main component of the connective tissue. It

5 functions as a supporting substance for cell growth and plays an important role as the matrix for manifestation of the functions of tissues and organs. Atelocollagen, which is prepared by pepsin treatment of acid-soluble collagen or insoluble collagen, has been widely used as substrate for animal cell culture.

10 Recently, studies on artificial organs have been developed. In particular, studies on artificial organs incorporating cells peculiar to each organ, that is to say, studies on hybrid organs, have been actively conducted. For instance, the development of a hybrid organ for the liver, in which hepatocytes are incorporated in keeping cell metabolic activities, has been attempted. In this case, it is important to stick the cells to the substrate while retaining the cell activity exhibited in vivo, and the type of substratum used is a fundamental consideration. As the substratum of liver cells, collagen extracted from the liver is reported to be best. (M. Rjkind et al, Connective Tissue Biomatrix: Its Isolation for Longterm Culture of 15 Normal Rat Hepatocytes, *J. Cell Biol.* 87, 255 (1980)).

20 So-called methods of cell technology such as cell culture and cell isolation currently occupy one of the important scientific technical fields in the advancement of life science. That is to say, effective cell culture and the techniques for isolating cells are the most important techniques in cell technology for the production of biologically active cell-derived substances. In the culture of animal cells, it is important to select a substratum with good adhesion to the cells in order to keep the original cell activity or in order to make the cells proliferate, and it is usually necessary to add bovine foetal serum to the culture medium in order to maintain the cell activity or cause cells to proliferate. However, recently, owing to difficulties in and 25 30

expense of obtaining bovine foetal serum, the establishment of a serum-free cell culture method has been sought. Recently, fibronectin, which is a kind of protein, has been noticed as a cell attachment factor and cell culture have been established in a fibronectin system instead of bovine foetal serum.

According to the present invention, a substratum for the culture of animal cells in a system in the presence or absence of bovine foetal serum comprises chemically modified collagen rich in negative charge or positive charge in culture condition.

The chemically modified collagen of the present invention enhances attachment of animal cells. For instance, mice fibroblast (L-cells) or macrophages ( $M\phi$ ) adhere to the modified collagen much better than unmodified collagen in the presence or absence of bovine foetal serum and modified collagen is thus superior as the substratum for cell culture. The substratum of the present invention can in particular also be used as the substratum of a serum-free culture method, so that the cell culture can be made at a cheaper cost and the difficulties involved in purchasing bovine foetal serum can be avoided. When fibronectin is used in place of bovine foetal serum, the attachment and proliferation of cells resulting from use of the chemically modified collagen substratum of the present invention are far superior to those of an unmodified collagen substratum. Furthermore, the chemically modified collagen substratum of the invention can detach adhering cells with a high efficiency so that the isolation and recovery of macrophages, which have been desired in the fields of immunology and tumorology, can be selectively made without cell injury.

All the figures of the accompanying drawings are graphs.

Fig. 1 shows the relations between the incubation time and cell adhesion rate of mice fibroblast (L-cells) by using various collagen substrata in the presence of bovine foetal serum.

Fig. 2 shows similar relations to those of Fig. 1 in the absence of bovine foetal serum.

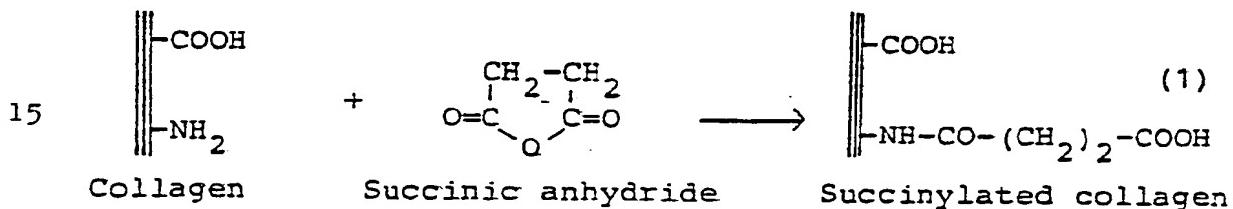
Fig. 3 shows the relation between the incubation time and the number of cells of mice fibroblast (L-cells).

Fig. 4 shows the relation between the incubation time and the cell adhesion rate of macrophages by using various collagen substrates in the presence of bovine foetal serum.

Fig. 5 shows similar relations to Fig. 4 in the absence of bovine foetal serum.

Native collagen, e.g. unmodified collagen, bears positive and negative charges in the side groups of the polypeptide chains. Basic amino acids, e.g. arginine, lysine and histidine provide positive charges and acidic amino acids, e.g. glutamic and aspartic acids, provide negative charges. The numbers of basic and acidic amino acid residues of unmodified collagen are 85 and 78 respectively per 1000 residues of amino acids, therefore basic amino acid is in an excess of 7.

One method for obtaining collagen rich in negative charges of the present invention is succinylation. As shown in the following scheme (1), this reaction is carried out by introducing a succinyl group on the -amino group of collagen with succinic anhydride and thus converting a free amino group to a free carboxyl group.



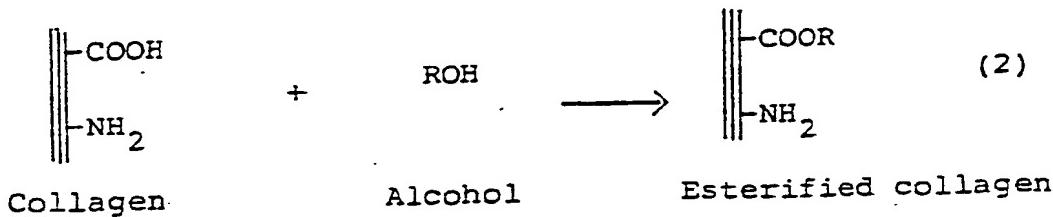
By this reaction, the succinylated collagen becomes rich in negative charge. When the succinylation has proceeded to completion, the resulting succinylated collagen has negative charges of 49 per 1,000 residues in excess at pH7.

20 It is preferable to succinylate more than 20% and particularly more than 40% of all the amino groups of collagen. If the degree of succinylation is inadequate, the adhering property of cells cannot be improved sufficiently.

25 Other methods for obtaining collagen rich in negative charge include carbamoylation, trifluoroacetylation and trinitrobenzoylation, all of which convert the amino groups to neutral derivatives, and the use of anhydrous maleic acid, which converts amino groups to carboxyl groups.

One method of obtaining collagen rich in positive charge is esterification by reaction of the carboxyl groups with alcohol in the

presence of an acid catalyst. This reaction is represented by the following reaction scheme (2),



In scheme (2), R represents a straight or branched univalent aliphatic hydrocarbon residue, preferably a methyl or ethyl group. When esterification is completed, negative charges are eliminated, and therefore, the positive charges of esterified collagen are in excess by 85 per 1,000 residues at pH7. It is preferable to esterify more than 20%, particularly more than 40%, of all carboxyl groups of collagen. If the degree of esterification is inadequate, the effect of enhancing cell attachment cannot be obtained.

Another method of obtaining the chemically modified collagen rich in positive charges involves esterifying the carboxyl groups by coupling them with nucleophilic groups via water-soluble carbodiimide, and, as a method of modifying the positive charge on the side chain of arginine, reaction with, for example butandione, 2,4-cyclohexadione or phenylglyoxal may be used.

The collagen material to be modified is preferably atelocollagen, which is prepared by solubilizing the insoluble collagen of bovine corium with pepsin, but acid-soluble collagen, which can be extracted with only acid, and insoluble collagen can also be used.

The animal cells that are incubated after adhering to the chemically modified collagen substratum of the present invention can be isolated and recovered. For instance, macrophages can be isolated from the mixed system of lymphocyte and macrophage, because only macrophage adheres selectively to the chemically modified collagen substratum by incubating in the presence of bovine foetal serum or fibronectin. Selectively adhering macrophage can be released and recovered in high yield by treatment with a bivalent cationic chelating agent such as EDTA (ethylenediaminetetraacetic acid) or EGTA (ethylene glycol bis (β-aminoethyl ether) N,N,N',N'-tetraacetic acid) without cell injury. By this method macrophage is highly selectively

isolated and recovered from the above mixed system. When unmodified collagen is used as a substratum it is impossible to isolate and recover macrophage because it does not efficiently adhere to unmodified collagen. In the absence of bovine foetal serum or fibronectin, it is difficult to detach 5 macrophage even when it is treated with a bivalent cationic chelating agent. Then, the highly selective isolation of macrophage can be attained by using the chemically modified collagen substratum rich in negative or positive charge, preferably in the presence of bovine foetal serum or fibronectin, and by treating the adhered macrophage with a bivalent cationic chelating 10 agent.

The following Examples illustrate the present invention. All parts and percentages in the Examples are on a weight basis unless otherwise implied. The word "Millipore" is a trade mark.

Example 1

15 Calf skin corium was crushed and then washed in 5% aqueous sodium chloride solution, followed by 1% aqueous sodium bicarbonate solution, to remove soluble materials, and then water. Thereafter pepsin was added at a ratio of 0.5% of dried collagen to skin corium suspension (pH 3.0) acidified with hydrochloric acid and insoluble collagen was dissolved at a temperature 20 between 20 °C and 25 °C with stirring. After dissolution, the solution was filtered successively through filter paper and Millipore filter of 1 µm and 0.45 µm aperture respectively and was allowed to stand overnight after adjusting the pH to 11.0 to inactivate pepsin. Then the pH of the solution was adjusted to 7.0-7.5, and the resulting precipitates of atelocollagen were 25 collected by centrifuging and washed in water. These precipitates were redissolved in dilute hydrochloric acid of pH 3, reprecipitated at pH 7.0-7.5, and collected by centrifuging.

10 g (dry weight) of atelocollagen was dispersed in 2 litres of a borax buffer solution of pH 10.0 and was succinylated by slowly adding a 5% 30 solution in acetone of succinic anhydride. During the reaction, 1 N sodium hydroxide solution was dripped in to keep the pH 10. As the reaction proceeded, the atelocollagen precipitate dispersed in the solution was dissolved. After the addition of anhydrous succinic acid was completed, the pH of the solution was adjusted to 4.5 to precipitate succinylated collagen. 55 The precipitate was collected by centrifuge, washed in water, redissolved in dilute hydrochloric acid of pH 3, reprecipitated at pH 4.5, and washed in

water to produce purified succinylated atelocollagen, which had a succinylation value of 80-90%.

10 g of atelocollagen that had been dried over silica gel under vacuum was immersed in anhydrous methanol containing 0.1N hydrochloric acid for 1 week. Methylated atelocollagen was formed. Its methyl esterification value was 60-80%.

Succinylated atelocollagen, methylated atelocollagen and non-modified atelocollagen were dissolved in dilute hydrochloric acid of pH 3 to make 0.3% solutions and the respective solutions were filtered through a 0.45 µm Millipore filter to remove bacteria. Plastics petri dishes were coated with each of the collagen solutions from which bacteria had been removed, and after drying aseptically by air, the dishes were irradiated by ultra-violet rays for 1 hour to crosslink the collagen. Furthermore, the collagen coated petri dishes were washed with Hank's salt solution three times.

2.5 × 10<sup>4</sup> cells of mice fibroblast (L-cells) were seeded per dish for culture and were incubated in culture media. Eagle culture medium containing 10% bovine foetal serum and Eagle culture medium not containing that serum were used as culture media. The incubation was carried out at 37 °C under 5% CO<sub>2</sub> gaseous phase. After incubating for a certain time, the culture liquid was discarded, the cells were washed in the same culture medium three times, and the cells detached from collagen substratum were washed out. The numbers of cells adhering to the substratum were calculated by counting the numbers of the cells washed out.

The relations of incubation time with the adhesion rate of cells were shown in Fig. 1 and Fig. 2. Fig. 1 shows the result in the presence of bovine foetal serum and Fig. 2 the result in its absence. In Figs. 1 and 2, the mark shows the result obtained from unmodified atelocollagen, the mark 0 shows the result obtained from succinylated atelocollagen the mark X shows the result obtained from methylated atelocollagen.

As is clear from Figs. 1 and 2, methyl-esterified atelocollagen and succinylated atelocollagen adhered to L-cells at a higher rate than unmodified atelocollagen (control) in the presence and absence of bovine foetal serum.

Example 2

The proliferation test of L-cells was conducted in the presence and absence of fibronectin by using culture dishes coated respectively with succinylated atelocollagen, methylated atelocollagen, and unmodified atelocollagen, which had been prepared by the method described in Example 1. To the culture dish coated with collagens, 0.5 ml of Hank's salt solution containing 100 µg/ml of human plasma fibronectin was added, and after allowing it to stand at 4 °C overnight and washing with Hank's salt solution twice, fibronectin was fixed to collagen substratum.

10        $1.5 \times 10^4$  cells of L-cells per culture dish were incubated by using serum-free Eagle culture medium, and the relation of the incubation time to the numbers of the cells was tested. The relation of the incubation time with the numbers of the cells was similarly tested on the collagen not fixed with fibronectin as a control. These results were shown in Fig. 3. In Fig. 15, the marks ▲, ● and ♦ represent the results obtained by unmodified atelocollagen fixed with fibronectin, succinylated atelocollagen fixed with fibronectin and methylated atelocollagen fixed with fibronectin, respectively. Further, the marks Δ, ○ and x represent the results obtained by unmodified atelocollagen, succinylated atelocollagen and methylated atelocollagen, respectively, none of which is fixed with fibronectin.

20       As seen in Fig. 3, the proliferation of L-cells was better in succinylated or methylated atelocollagen substratum than in unmodified atelocollagen in both media, with and without fibronectin. Especially, it was suggested that L-cells proliferated very well on the chemically modified atelocollagen substrata in the medium containing fibronectin.

Example 3

30       The adhesiveness of macrophage to the substratum was tested by using culture dishes coated with succinylated atelocollagen, methylated atelocollagen and unmodified atelocollagen, respectively. Exudate of mice abdomen was taken and the cells precipitated by centrifuging were dispersed in RPMI 1640 culture medium (made by Nissui Pharmaceutical Co. Ltd.) containing or not containing 10% bovine foetal serum respectively. To each of the culture dishes, 1.5 ml of culture medium containing  $1 \times 10^6$  cells of macrophage was added and incubated at 37 °C under a 5% CO<sub>2</sub> gaseous phase. After incubation, the culture dishes were washed with culture medium, the numbers of not-adhering macrophages were counted and the numbers of adhering macrophages were calculated by subtracting them from the numbers of the inoculated cells.

The relation between the incubation time and adhesion rate of macrophage is shown in Figs. 4 and 5. Fig. 4 shows the result obtained in the presence of bovine foetal serum and Fig. 5 shows the result obtained in its absence. In Fig. 4 and Fig. 5, the mark  $\Delta$  represents the result obtained from unmodified atelocollagen, the mark 0 represents the result obtained from succinylated atelocollagen the mark x represents the result obtained from methylated atelocollagen.

As it is clear from Figs. 4 and 5, macrophage could adhere to succinylated collagen or methylated collagen in the presence or even in the absence of bovine foetal serum at a high rate, and, when incubated for longer than 60 minutes, adhesion of more than 90% was shown, but macrophages hardly adhered at all to unmodified collagen.

The exudate of the abdomen used in Example 3 contained macrophages in about 50% of all the cells and lymphocytes in the remained 50%. As the lymphocytes did not adhere to chemically modified collagen, the macrophages could be isolated completely from the lymphocytes by recovering the adhering macrophages.

To succinylated atelocollagen, methylated atelocollagen and unmodified atelocollagen, the macrophages were made to adhere by incubating at 37 °C for 3 hours in the presence of 10% bovine foetal serum. 1.5 ml of phosphate buffer solution containing 0.5 millimole/l of EDTA was added to the culture dishes with adhering macrophages and was kept at 37 °C for 10 minutes to detach macrophages. The detached macrophages were recovered and their numbers counted, and the recovery rate of the macrophages and their purity were calculated.

Table 1

Substrates	Recovery rate of macrophages (%)	Purity of recovered macrophages (%)
Succinylated atelocollagen	41	94
Methylated atelocollagen	48	92
Unmodified atelocollagen	3	88

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As will be understood from Table 1, macrophages with higher purity were obtained when succinylated or methylated atelocollagen was used as a substratum, and the recovered macrophages were not injured.

CLAIMS

1. A substratum for cell culture of animal cells in a system in the presence or absence of bovine foetal serum that comprises chemically modified collagen.
2. A substratum according to Claim 1, in which the chemically modified collagen is collagen rich in negative charge in culture condition.
3. A substratum according to Claim 1, in which the chemically modified collagen is collagen rich in positive charge in culture condition.
4. A substratum according to Claim 2, in which the chemically modified collagen is succinylated collagen.
5. A substrum according to Claim 3, in which the chemically modified collagen is esterified collagen.
6. A substratum according to Claim 4, in which more than 20 mol% of the total amino groups of collagen are succinylated.
7. A substratum according to Claim 5, in which more than 20 mol% of total carboxyl groups of collagen are esterified.
8. A method for culturing and isolating cells comprising causing animal cells to adhere to chemically modified collagen, incubating the animal cells and treating the animal cells with bivalent cationic chelating agent to isolate and recover the cells.
9. A method according to Claim 8, in which macrophages mixed with lymphocytes are incubated and only the macrophages are selectively isolated and recovered.
10. A method according to Claim 8 or 9, in which the bivalent cationic chelating agent is EDTA or EGTA.

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11. A method according to Claim 8, 9 or 10, in which the adhesion and incubation of animal cells are carried out in the system of presence of bovine foetal serum or fibronectin.

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FIG. 1

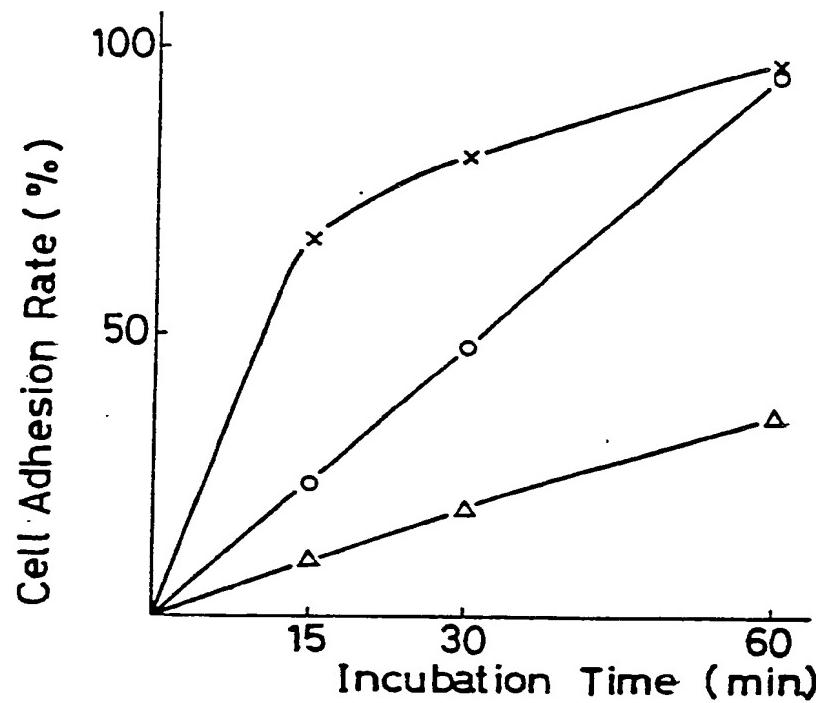
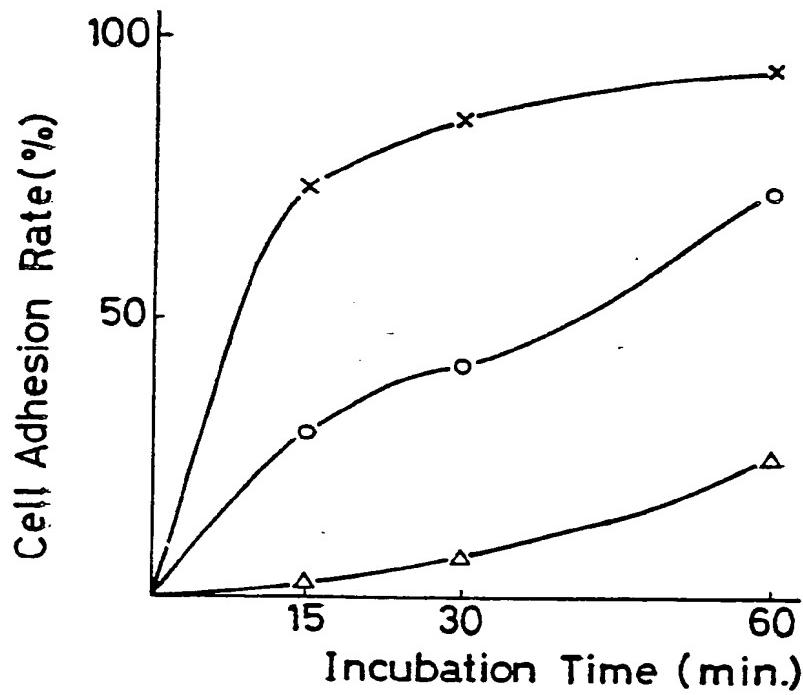


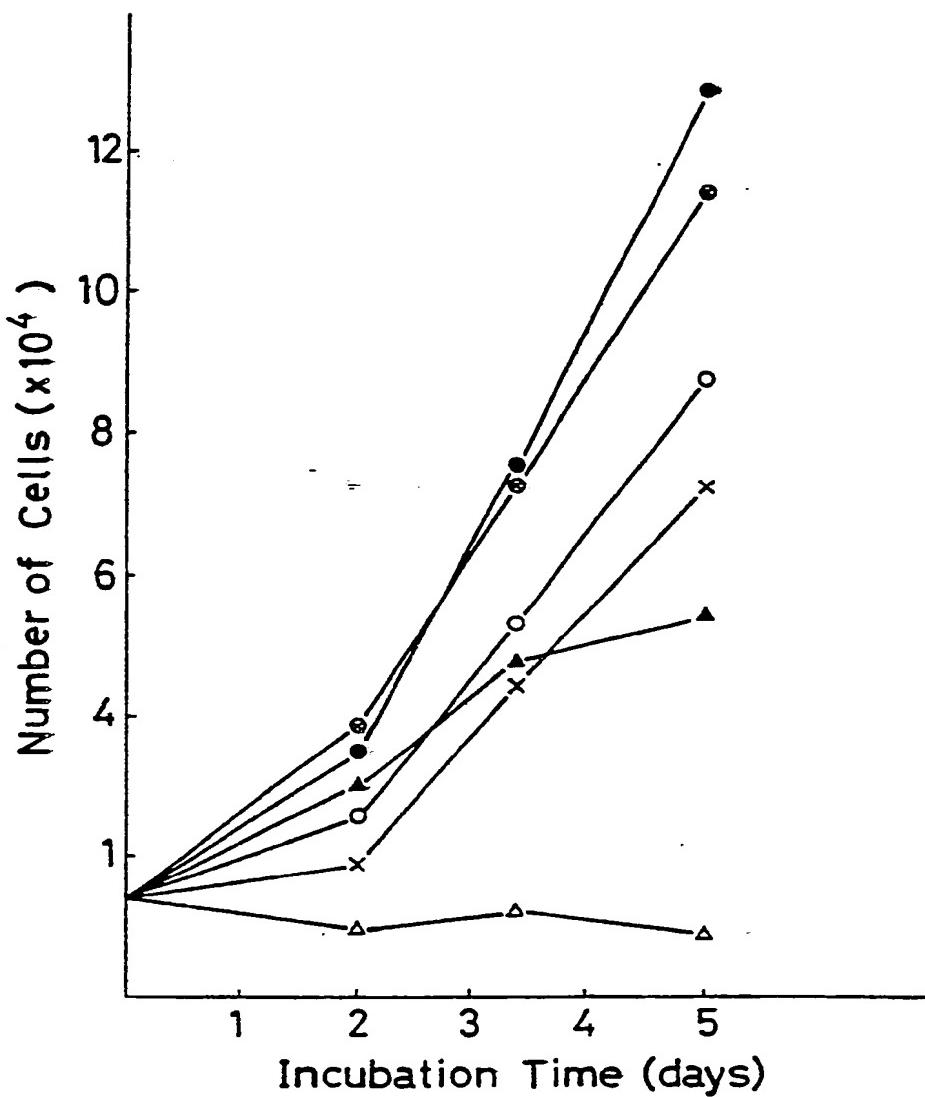
FIG. 2



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FIG. 3



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FIG.4

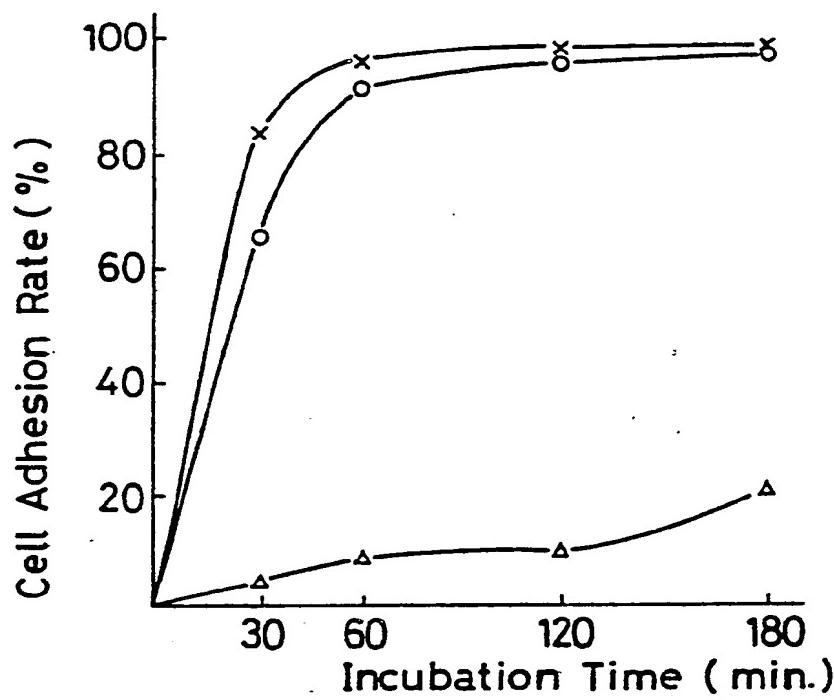


FIG.5

